**Motivation**

III-V photovoltaic devices display a significantly higher efficiency than commercially available solar cells. Germanium substrates on which III-V devices are grown represent a significant fraction of overall production costs. The solar cells can be removed from the Ge substrate through a process called spalling. Reusing the substrate after spalling requires highly controlled surface quality.

**Research Goal**

- Provide a baseline roughness for post-spalled Germanium substrates using atomic force microscopy.
- Determine trends between surface roughness and spalling parameters.
- Evaluate the effect of surface treatments on surface quality.

**Methods**

**Spalling Germanium:**
- An electro-plated Ni layer creates a strain mismatch that allows a fracture to propagate through the substrate at a certain depth.
- Spalled Ni-Ge film was mounted, polished, and used to optically measure spall depth.

**Measuring Surface Roughness:**
- Tapping mode AFM uses an oscillating cantilever to map out the surface of the spalled substrate. The image is then imported into an analysis software called Gwyddion.

**Effect of Applied Current Density on Roughness**

<table>
<thead>
<tr>
<th>Current Density (mA/cm²)</th>
<th>RMS Roughness (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Spalled Ni</td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td></td>
</tr>
</tbody>
</table>

**Effect of Annealing on Roughness**

<table>
<thead>
<tr>
<th>Annealing Temperature (°C)</th>
<th>RMS Roughness (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Annealed</td>
<td></td>
</tr>
<tr>
<td>250</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td></td>
</tr>
<tr>
<td>700</td>
<td></td>
</tr>
</tbody>
</table>

**Results**

- Spalled Ge using Ni-Cl bath tends to be rough.
- Spalled Ge using Ni-P bath tends to be less rough.
- Samples plated in the Ni-P bath resulted in lower roughness.
- All samples displayed varied surface features, including flatter areas and areas of jagged peaks.
- Since spall depth does not effect roughness, other engineering parameters should be evaluated.
- Annealing in a H₂ environment is not a promising method of preparation for substrate reuse.
- Annealing samples at 600, 650, and 700 °C develops unexpected surface features.
- At 650 °C the Ge substrate began evaporating and formed undesirably rough pits.

**Conclusion**

- Samples plated with a high current density in the Ni-Cl bath tended to have a high RMS.
- Spalled Ge using Ni-P resulted in lower roughness.
- These surfaces will need to be looked at more closely.
- Ni-P bath and roughness at different current densities.
- Annealing in H₂ and diluted H₂/N₂ atmosphere and measuring subsequent roughness.

**Future Work**

- Chemical etchants are currently being investigated to refine the surface of spalled Ge for regrowth.
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**Acknowledgment**

Chloe Castaneda, Corinne Packard¹², Dustin Crouse¹, Cassi Sweet¹, Nikhil Jain²
¹Colorado School of Mines, ²National Renewable Energy Laboratory